"Some Remarks on the Mechanism of Respiration." By F. Le Gros Clark, Surgeon to St. Thomas's Hospital, Member of Council and of the Court of Examiners of the Royal College of Surgeons, and late Hunterian Professor of Surgery and Pathology in the College, and Examiner in Surgery at the University of London. Communicated by P. Martin Duncan, M.B., F.R.S., Professor of Geology in King's College, London. Received April 18, 1871*.

1. In performing some experiments on recently slaughtered animals, for the elucidation of a subject which I was then engaged in investigating, I was struck with the remarkable arched tension of the diaphragm, a condition which continued unabated until air was admitted into the pleural spaces, and then it became flaccid and descended. This altered condition was attended by collapse of the lungs, which receded from the thoracic walls, and occupied a much smaller space than previously.

2. In order to measure the quantity of air expelled from the lungs in the preceding experiment, and to ascertain how far the collapse of the lungs and the altered condition of the diaphragm were dependent on each other, the following experiment was performed. The trachea of a sheep, immediately after death, was exposed in the neck, divided, and tied over a glass tube, which was put in communication with a graduated receiver placed under water, and guarded by a stopcock. The pleuræ were then opened, and as air entered the diaphragm became flaccid; but the lungs remained unchanged in position and form. The stopcock was then opened, and a rush of air, displacing the water in the receiver, was accompanied by collapse of the lungs. The quantity of air thus forcibly expelled was from ten to twelve cubic inches.

3. The interpretation of this experiment is—

(*a*) That the passive tension of the diaphragm is due to the atmospheric pressure on its abdominal surface, which is not counterbalanced by a corresponding pressure on the opposite or thoracic surface, until air is admitted into the pleuræ.

(*b*) That the lungs retain their supplemental air by virtue of this tense condition of the diaphragm, the elasticity of the former being resisted by the tension of the latter.

(*c*) That the contractility of the lungs, tending to the expulsion of the supplemental air, removes the atmospheric pressure from the upper surface of the diaphragm, and thus produces and maintains its arched form and tense condition.

(*d*) That as soon as the pressure on the inner and outer surfaces of the lungs was equalized, by the admission of air into the pleuræ, their contractility forced out the supplemental air; and the quantity thus expelled

* Read May 25, 1871. See abstract, vol. xix. p. 486.

may be accepted as an approximate measure of the elasticity of these organs.

(*e*) That the diaphragm was rendered flaccid by the admission of air into the pleuræ, independently of the collapse of the lungs.

4. Thus there exists a constant antagonism between the atmospheric pressure on the interior of the lungs and their elastic and contractile properties, tending to the expulsion of the air they contain; and this expulsive power is limited by the resisting tension of the diaphragm. These several conditions are in no degree influenced by the direct admission of air into the abdominal cavity; for the trachea being treated as in the former experiment before the abdomen was opened, and an aperture being then made into the peritoneum, the abdominal walls rose as air rushed in, but no air was expelled from the lungs. The expansion of the abdomen under these circumstances is especially remarkable in oxen when turned on their back, and is probably in great measure due to the position favouring the expansion of the lower costal region.

5. In the recognition of the above facts, I think that the extremely tense condition of the diaphragm has not received the notice which its practical importance deserves. Independently of being the agency by which the supplemental air is retained in the lungs, the resistance thus offered limits the encroachment of the abdominal viscera on the thoracic cavity; and by this same property, combined with the broad and inseparable attachment of the central tendinous expansion to the fibrous pericardium, the heart is preserved from being impeded in its movements in the various stages of respiration.

That the tension in question fulfils these functions is exemplified pathologically as well as physiologically. It would indeed be impossible, without giving due weight to this property of the diaphragm, to account for the trifling interference, comparatively speaking, that pregnancy, or the presence of large ovarian tumours or ascitic accumulations, exercises over the mechanism of respiration; and it would appear still more surprising that the sudden removal of such distension, and with it the pressure on the diaphragm, is not attended by more serious consequences. Yet the respiratory mechanism is scarcely influenced appreciably even by the sudden collapse of an enormous ovarian cyst; and this is accounted for by the passive tension of the diaphragm, which alike resists encroachment from below and refuses the solicitation to descend which the removal of the pressure would seem to offer.

6. In the action of the diaphragm this tension is an essential condition, in order that there may be no waste of power, but that its earliest contraction may be accompanied, at once and simultaneously, by the entrance of the tidal air into the lungs; and it would seem probable that, for ordinary expiration, the suspension of its contraction and consequent return to its normal state of arched tension is alone sufficient.

7. But further considerations present themselves in reviewing this pro-

perty, in association with the attachments of the diaphragm, and the relations of other muscles credited severally with functions in both inspiration and expiration.

8. The thoracic parietes, both osseous and cartilaginous, are movable, admitting of an increase or diminution in the circumference of the chest; and the diaphragm is attached, by its circumference, to the chest-walls. As the force by which the tensely arched diaphragm is rendered plane is necessarily considerable, it may be asked, does the contraction of this muscle under any circumstances draw in the ribs? and why does it not do so always? I believe the answer to the first inquiry to be, that it does, under some circumstances, draw in the ribs; and the explanation of the second must be sought in a consideration of the agency of other muscles engaged in inspiration, to which attention will be presently directed.

9. The property of the diaphragm under consideration—its passive tension—is engaged in restoring the equilibrium of rest after a deep expiration. The supplemental air is expelled from the lungs chiefly by the action of the abdominal muscles, the circumference of the chest undergoing no appreciable change except at its lower part, where it is directly acted on by these muscles. When they are relaxed, and the lower costal region again expands, the diaphragm asserts its passive influence, by drawing in so much air as the counter-resistance of the contractility of the lung-tissue will permit.

10. But this agency is somewhat more complex than would appear from the above statement. The passive tension of the diaphragm is such that it would probably be sufficient to resist the efforts of the abdominal muscles to force it upwards, without the cooperation of another cause, which is the altered condition of the chest-walls. The lower ribs are perceptibly drawn inwards, as stated, when the supplemental air is expelled from the lungs; and, as a necessary consequence, the horizontal portion of the diaphragm is relaxed, and thus placed in a condition which permits of its being forced upwards, so as to compress the lungs.

11. But the deepest inspiration is also attended by hollowing or drawing in of the epigastrium; and the increasing circumference of the lowest costal region, which is limited as compared with the upper, is almost arrested before the act of forced inspiration has attained its maximum; and the rise in the abdomen is likewise suspended before this climax is reached. These conditions are due, I apprehend, to the combined effect of atmospheric pressure on the relaxed abdominal walls, concurrently with the extreme contraction of the diaphragm, overcoming the resistance of the intercostal muscles, and drawing in the lower ribs.

12. As exemplifying, in a remarkable and interesting way, the foregoing observations, I may mention the case of a patient recently an inmate of St. Thomas's Hospital, in whom there was fracture, with displacement of the sixth cervical vertebra, by which the cord was compressed.

He survived the injury less than three days, and there was complete paralysis of motion and loss of sensation below a line level with the nipples; the movement of the arms was also impaired. "The walls of the chest, across and below the nipples, were retracted at each inspiration." I quote the words of the Hospital Registrar; but I repeatedly proved this, and demonstrated the fact to others, by placing around the chest, just over the nipples, a tape, which became relaxed at each inspiration, to the extent of at least half an inch. The inspirations were short and sudden the expirations prolonged, and latterly intermittent. This is not the only instance in which I have observed this phenomenon under similar conditions.

The following case has more recently come under my observation, and I give it according to the report of Mr. Anderson, the Surgical Registrar of the hospital :—" F. F., aged 58, a bricklayer, was admitted into St. Thomas's Hospital in February 1871, having fallen from a considerable height, and struck some projecting object in his descent; he remained incapable of movement, though perfectly sensible. The lower limbs were paralyzed, and the movements of the upper extremities were impaired; and he complained of great pain shooting from the neck into the upper extremities. In breathing, the whole chest was very perceptibly drawn in during inspiration, and the abdomen became more prominent than is normal. The chest was slightly raised as a whole, and the sterno-mastoids were seen to act strongly. The lower ribs were not drawn downwards, but appeared to be pulled directly inwards, or inwards and slightly upwards. In expiration the chest-walls appeared to relax, as if from the cessation of some contracting influence. The respiration, as a whole, was jerking, but not increased in frequency. Subsequently the chest appeared to act unilaterally, as if from unequal action of the two sides of the diaphragm, the ribs on the left side being drawn inwards during inspiration, whilst the right half of the thorax was thrust outwards passively. He survived the accident about sixty hours; and the cord was found crushed between the fifth and sixth cervical vertebræ, which were fractured."

This peculiarity in the diaphragmatic breathing must be due, in the main, if not entirely, to the suspension of the intercostal action, whereby the ribs are left at liberty to be acted upon, and thus drawn in by the contraction of the diaphragm.

13. I would remark, as bearing upon the foregoing observations and those I am about to make, that in the unfettered adult body, in the erect or sitting posture, the sphere of respiratory movements, as seen and measured, is chiefly limited to the region which is bounded above by a horizontal line extending outwards from the lower extremity to the sternum, and below by a similar line extending from the umbilicus to the anterior spine of either ilium. In the recumbent posture, when the abdominal muscles are relaxed, the movement extends lower over the abdomen. Yet the measurements are by no means commensurate with the apparent move-

ments. The deeply notched form of the chest below, with its movable elastic boundary of cartilage, is well adapted to admit of these necessary movements of alternate expansion and contraction.

14. A difference of opinion exists as to the action of the intercostal muscles, some physiologists assuming that the external and internal sets of muscles act independently of each other and as antagonists; others supposing that different parts of the same muscle perform diverse functions. I am disposed to believe that both these conjectures are incorrect; and that Haller is right in his opinion, that both sets of intercostals act as muscles of inspiration. They act, in concert with the scaleni, in drawing the ribs upwards; they also approximate them, and rotate them on their axes,—a result which is facilitated by the increasing mobility of each pair of ribs as we descend from the first to the last. The effect of such action is to afford a fixed circumference from which the horizontal portion of the diaphragm can act without drawing the ribs inwards; at the same time that the general capacity of the chest is augmented, though its vertical diameter, so far as the intercostal action is concerned, is shortened; and the crura of the diaphragm must also aid importantly in steadying and fixing the central tendon during inspiration, and in preserving the pericardium from that encroachment to which it would be liable if the central tendon were not thus fixed at its back part, and drawn downwards from the chest.

15. But the action of the intercostal muscles, which has been a subject of so much dispute, will repay a more careful examination.

The posterior portion of the external intercostals, reaching from the angles to the tubercles of the ribs, unaccompanied by the internal intercostals, has an action similar to that of the levatores costarum, the upper of the two ribs to which each fibre is attached forming a fixed point from which the lower rib may be influenced in direction. The anterior part of the internal intercostals, passing between the costal cartilages unaccompanied by the external intercostals, must, from the direction of the fibres in relation to the direction of the portion of rib to which they are attached, act, like the posterior portion of the external intercostals, in elevating the ribs. (Here diagrams were employed to illustrate these points.)

It is hence obvious that the combined influence of these portions of the two muscles will be, where the fixed point is taken from the upper of the two ribs to which they are attached, to swing the rib in an opposite direction upon an imaginary axis drawn through the spinal and sternal attachments, taking a true rib as a type. The entire length of the external intercostals will also act with the levatores costarum, and produce the effect, in forced inspiration, of raising the anterior end of the rib, and thus thrust forward the sternum.

In the contraction of the decussating portions of each set of muscles simultaneously with the others, we get the diagonal of the action of both as the result of their joint action, the upper of the two ribs to which each pair of muscles is attached being relatively fixed.

16. The summary of the action of both sets of muscles may be thus stated:—

(1) They increase the transverse diameter of the chest, by raising the curve of the ribs more nearly to a level with the attachment of the ends. All the fibres must assist in this action, but especially the external intercostals and the anterior part of the internal intercostals.

(2) They increase the antero-posterior diameter of the chest by raising the anterior attachmeut of the ribs, and with them the sternum, more nearly to a level with the posterior attachment, thereby also separating the costal cartilages of the lower true and false ribs, and thus widening the interval which separates them on either side of the ensiform cartilage. The posterior fibres of the external intercostals will act with the levatores costarum and (in forced inspiration) with other indirect agents.

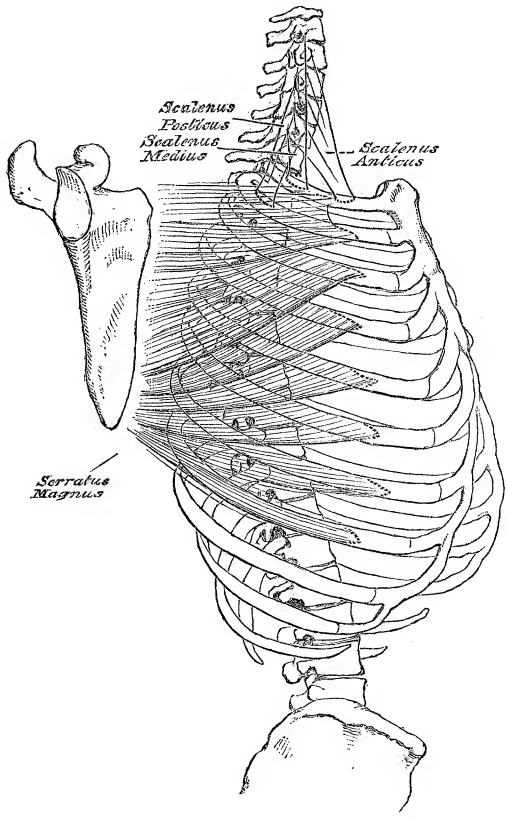
(3) They assist in rotating the ribs outwards, when they elevate them.

(4) They fix the thoracic walls. This action is a most important one: —*a*, by giving, when needed, a fixed attachment for the various muscles which are connected to the chest, and which have a double action, according to the relative mobility of their origin and insertion; *b*, by preventing the diaphragm from drawing in the walls of the chest during ordinary inspiration; *c*, by resisting the atmospheric pressure during inspiration, by virtue of the tension of the intercostal spaces.

17. The serratus magnus is usually described as a powerful muscle in forced inspiration, when the scapula is fixed; but from a careful study of the direction of its fibres, from observation of its action in deep breathing, and (so far as the experiment may be depended on) under the influence of electro-galvanism, I venture to question the correctness of this generally accepted description. The direction of the component parts of this broad muscle would seem to indicate that none but the lowest digitations can assist in elevating the ribs or increasing the capacity of the chest; on the contrary, the contraction of the upper digitations must rather tend to draw the ribs downwards, and to aid in expiration. It is true that extreme elevation of the scapula somewhat alters the relations of the origin and insertion of this muscle, but not to such a degree as to impart to it its assumed power, even if such elevation were, as it is not, a necessary condition in forced inspiration. Further, a careful observation of the well-marked digitations of this muscle in a well-developed and thin person, during the act of forced inspiration, failed to discover, either tangibly or visibly, any contraction of their fibres, which was very distinctly marked when the scapula was moved. In stimulation of the muscle by electro-galvanism, though the scapula was freely jerked and moved about, no movement whatever of the ribs or interference with respiration resulted. But it must be admitted that not much importance can be attached to this experiment, as the more movable attachment of the muscle would necessarily yield most readily during its contraction. Indeed this remark applies to all experiments of this nature, in which a single muscle is stimulated to

contract, without reference to the cooperating or antagonistic action of other muscles. Such isolated experiments are therefore not only unsatisfactory, but often delusive.

Fig. 1.



But the question which I have raised may be discussed a little more in detail. The inferior angle of the scapula reaches as low as the eighth rib, while the thorax is in a state of repose after an ordinary inspiration. The lowest digitation of the serratus magnus, arising from the extreme end of the angle, follows the course of the eighth rib, and is attached to it. Assuming for a moment the capability of the serratus magnus to act in inspiration, it would be necessary for this result that the vertebral costa of the scapula be drawn back and rigidly fixed by the rhomboids &c.; the consequent extension of the fibres of the serratus is further enhanced by the expansion of the chest during forced inspiration—a condition which is not consistent with what is observed in other muscles during a passive

imitation of their action. In other words, the relation of the fibres of this muscle to the ribs is such, that a passive imitation of the action ascribed to them is to make tense and not to relax them; they have to run over a longer surface—a wider barrel. But the fact is, that the lower angle of the scapula is neither fixed nor in any marked degree drawn up in deep inspiration; but the angle and vertebral costa are carried further away from the spine; and as the serratus is, as already remarked, not visibly or tangibly in action, this result can be accomplished only by the costal attachments of the muscle being removed to a greater distance from the spine, by the expansion of the chest. Each digitation of the muscle acts at an increasing disadvantage as we ascend from the last to the first; therefore, if the lowest digitation is incapable of acting as an elevator of the ribs, the same negative conclusion must, *à fortiori*, be arrived at as regards the rest of the muscle.

It is no doubt true that the serratus is in action during deep inspiration, when the arm is raised. But this contraction is persistent during expiration also; and the action in each instance is explained by the fact that this muscle is required to assist the trapezius in rotating outward the lower angle of the scapula, and maintaining it in that position, in order to accommodate the relation of the glenoid cavity to the head of the humerus, and to afford a fixed attachment for the action of the deltoid. The chest is, under these circumstances, the relatively fixed origin of the serratus, and the scapula its movable insertion on which it rests.

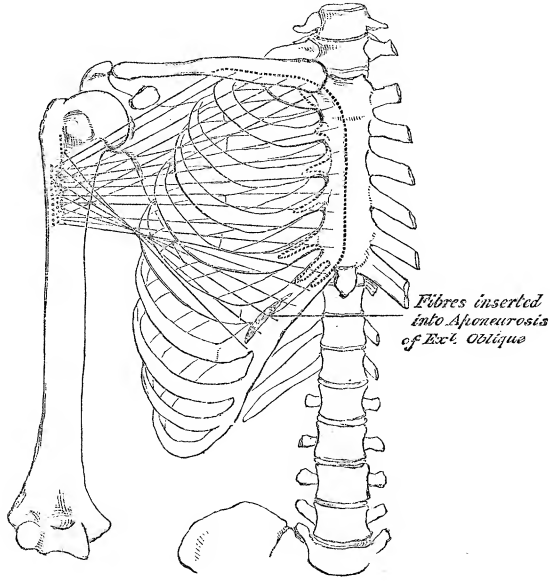
18. A parity of reasoning applies to the pectoralis major muscle. This muscle is described as assisting in forced inspiration, by raising the ribs and dilating the chest. I think this assumption incorrect for the following reasons:—

(1) A necessary condition to the action of this muscle on the thorax is the relative immobility of the scapula and humerus; but in a healthy chest the most powerful inspiratory effort may be made without any such assistance; and the pectoral fibres may be felt and seen to remain during this effort in a state of complete inaction. When the humerus is fixed, the fibres are in action; but this condition is due to their agency in fixing the bone.

(2) The clavicular and upper portion of the sternal fibres may be considered as incapable of raising the ribs, whilst the arm is not elevated; the lower fibres alone can be supposed to possess this property or power. Now the lowest fasciculus is not attached to the ribs, but terminates in the aponeurosis of the abdomen by a broad fibrous expansion: this portion of the muscle can take no part in raising the ribs. The set of fibres above these arises from the sixth rib and its cartilage, and from the adjacent portion of the sternum: they are inserted into the upper part of the outer margin of the bicipital groove, in a horizontal plane with the sternal attachment of the third rib and the spinal attachment of the sixth rib. In deep inspiration the effect of forward movement of the sternum will nearly, if

not entirely, correspond with that of the elevation of the anterior attachment of the rib; so that the pectoral fibres will not be appreciably shortened, and consequently cannot materially assist in the inspiratory effort. If we ascend a step higher, to the fifth rib, it would appear that the pectoral fibres will rather resist than assist in the act of inspiration; still more is this the case nearer to the clavicle.

Fig. 2.



When the arms are raised above the head, the great pectoral muscles would have an undoubted action in elevating the ribs; but such a position is never assumed, even in disease, for the purpose of assisting inspiration.

19. Indeed the same may be said of the serratus magnus and pectorales as of the intercostals and other muscles credited with agency in respiration,—that their action must be studied in relation to that of other muscles, which have an important influence in modifying or even in determining their action; and bearing this in mind, and for the reasons adduced, I think it very questionable whether any of these muscles can exercise an influence, except under special conditions and to a very limited extent, in the act of inspiration.

20. The conclusion to which the foregoing observations point is, that the act of inspiration is, under all circumstances, essentially, perhaps exclusively, dependent on the special muscles appropriated to this function—muscles which are competent, without extraneous aid, to answer the appeal made to them in emergencies as well as under ordinary circumstances.

21. The action of the scalenus anticus, a powerful muscle, is essential

for fixing the first rib in inspiration; and it may be distinctly felt so acting in a thin neck, during forced inspiration, when the rib into which it is inserted is raised with the sternum. The scalenus posticus has a similar action on the second rib. The pectoralis minor, when the coracoid process is fixed, and some few other unimportant muscles, may assist in the elevation of the ribs. In the absence of fixation of the upper or lower ribs, if such condition ever exist, it is difficult to resist the conclusion that the action of the intercostals must necessarily limit the capacity of the chest, by drawing the ribs towards each other and rendering the intercostal spaces rigid.

Of the lower ribs, experiment has satisfied me that both the tenth and eleventh are raised during deep inspiration—the latter in a less degree than the former. The intercostal spaces between the tenth and eleventh, and between the eleventh and twelfth ribs, are consequently widened considerably. The last rib is probably fixed by the attachment of the quadratus lumborum: this rib feels prominent and fixed during deep inspiration; whereas, under ordinary circumstances, it is loose and not easily felt.

With the view of ascertaining the mobility of the sternum, and of comparing the antero-posterior and lateral movements of the chest, I procured a large pair of callipers, with a fixing screw attached. I may thus state briefly the result of my observations on healthy individuals.

22. There is no perceptible increase in the antero-posterior diameter of the chest in ordinary inspiration. The antero-posterior diameter of the chest is augmented perceptibly in forced inspiration at the junction of the second rib with the sternum, and but slightly more so at the junction of the sixth rib with the sternum. The mean of the experiments gives about $\frac{5}{8}$ of an inch, the variation being from $\frac{3}{8}$ to $\frac{7}{8}$ between a state of rest and that of deep inspiration. (An explanatory diagram was here shown.)

The difference between expiration and a state of rest, in either of the above measurements, is about the same as between rest and inspiration, the latter being somewhat in excess, especially at the lower true ribs.

The lateral diameter of the chest, in deep inspiration, is augmented, absolutely as well as relatively, to a greater degree than the antero-posterior, in the proportion of 6 or 7 to 5, opposite the fifth or sixth rib; but the maximum increase appears to be attained at about the eighth rib, where the mean is as 10 to 5.

The movements of the sternum follow those of the costal cartilages, and are dependent on them. These movements, which occur in forced inspiration only, consist in an alternate advance and sinking of the bone, which is most marked at its lower extremity.

23. The first rib is certainly capable of elevation during inspiration, and the anterior and middle scalenus muscle performs this office: probably its agency is limited, in ordinary inspiration, to fixing the rib. In forced inspiration, the action of the clavicular portion of the sterno-mastoid is first apparent, and subsequently that of its sternal portion.

24. In ordinary expiration no muscular action is exerted; but in extraordinary expiration the ribs are drawn down by the abdominal muscles, at the same time that the abdominal viscera are pressed upwards. The intercostals assist in this act when the lower ribs are thus fixed. The levator ani is an essential auxiliary in forced expiration. I do not attach much value to the agency of the triangularis sterni and serratus posticus inferior as muscles of expiration. I am disposed rather to regard them as agents in steadying the ribs for the diaphragm, and as antagonists, severally, to the pectoral and latissimus dorsi muscles, thereby affording them a more fixed attachment at their origin.

25. The generally received assertion that there is a marked difference in the respiration of the two sexes, *i. e.* man and woman, confirmed, apparently, by the observations of Hutchinson on young girls, has always struck me as very remarkable; for, whatever hypothesis may be adduced to favour the relative advantage of such peculiarity, as regards woman, there certainly is no anatomical difference, either in the *natural* osseous conformation of the chest or in the muscular apparatus of respiration, to account for the predominance of the abdominal type of breathing in the male, and of the thoracic type in the female.

It naturally occurs to any one, in contemplating this circumstance, to attribute something to the peculiar dress of civilized women—the fashion of compressing the lower part of the chest, which is universal. There can be no doubt that this compression, commenced as it is at a very early period amongst *all* classes, long before the development of the skeleton is completed, must exercise a permanent influence in altering the form of the chest, and must thus impart a factitious reality to that which is not natural. I believe that the early age at which this compression is begun, even amongst the lower orders, as I have ascertained by inquiry, has possibly misled so careful an observer as Hutchinson. I have repeated his experiments on young boys and girls, but with results at variance with those which he obtained. These results may be thus stated.

26. In *ordinary respiration* the upper costal respiratory movements are equal in male and female; they are increased in both by girding the abdomen and lower ribs with a roller. The lower costal movements are also equal in the two sexes, and are not perceptibly affected by the action of the roller.

The difference in the thoracic girth between ordinary expiration and inspiration is very slight, indeed scarcely perceptible.

27. In *extraordinary respiration* the costal movements, both upper and lower, are much greater in forced inspiration in the male than in the female. The lower costal movements are much interfered with, in both, by the compression of the abdomen and lower part of the chest, while the upper costal movements are exaggerated.

I may add that, in the adult female, there is, as might be expected, a striking difference in the relative mobility of the chest and abdomen, when

the respiratory movements are observed whilst the usual tight dress is worn, and when the figure is at liberty to expand more naturally on removal of the dress.

28. Moreover, the form of the bust in the female lends a further aid to the influence of dress, by exaggerating the thoracic movements. Thus in stout women with full bosom, the rise and fall of the chest is much more apparent than in those in whom the bosom is spare and ill developed. This may be partly accounted for by the greater interference which is due to the increased compression exerted to reduce the size of the waist by stout women, but not wholly so. An artificial arrangement on the upper part of the chest of the male, by which prominence is given to this region, when the waist is compressed, at once exhibits distinct thoracic movements which were not otherwise perceptible. I am disposed, therefore, to believe that the asserted natural difference in the respiration of the two sexes is due to the altered form of the chest, consequent on compression, and to the habitual confinement of the lower costal region, which necessitates the habit of thoracic breathing. It is to be regretted that experiments to determine this question have not been conducted in some uncivilized community, which has not attained to the cultivated refinement of endeavouring to improve the natural symmetry of form at the expense of health and comfort. I am not aware that any such attempt has yet been made.

P.S.—Since writing the above, I have had the opportunity of conversing with M. Duchenne, who performed some experiments with electro-magnetism at St. Thomas's Hospital to demonstrate the action of various muscles.

He expressed himself strongly respecting the action of the intercostals as exclusively muscles of inspiration. This opinion is based partly on experiments performed upon decapitated criminals, and partly on clinical observations in cases of muscular atrophy. Immediately after death M. Duchenne applied the stimulus of an interrupted current to the intercostal muscles, with the result of raising the ribs. He stated that he isolated as far as possible the external from the internal set of muscles, and found stimulation of either set produced the same result. I give these statements as I received them, but I did not witness the experiments referred to.

The following are the chief points, either disputed or not previously recognized, which it is the object of the preceding observations and experiments to establish:—

1. The normal state of the diaphragm, when at rest, is that of arched tension; and this condition is due to the elasticity of the lungs resisting the atmospheric pressure on its thoracic surface.

2. This tension is such that the diaphragm cannot be forced upwards whilst the ribs are fixed; and is exerted in drawing the ribs inwards when the intercostal muscles are relaxed.

3. The results due to this passive tension are that (*a*) it retains the supplemental air in the lungs; (*b*) it limits the encroachment of the abdominal viscera on the thoracic cavity; (*c*) by virtue of the attachment of the pericardium to the cordiform tendon, the uniform calibre of this bag is secured, and the heart is thus protected from being impeded in its movements during respiration, the crura taking part in maintaining this condition when the muscle contracts; (*d*) it economizes active power in inspiration.

4. *Inspiration.*—When the upper ribs are fixed by the scaleni, both sets of intercostal muscles act in increasing the transverse diameter of the chest, by raising the curve of the ribs and the sternum.

They rotate the ribs outwards.

They fix the thoracic walls, and thus antagonize the tendency of the diaphragm to draw inwards the ribs to which it is attached. A fixed circumference is thereby secured, from which the diaphragm acts in altering its own form; and this is one of the most important functions of the intercostal muscles.

They assist in expiration when the lowest ribs are fixed by the abdominal muscles.

5. The scalenus anticus and posticus (especially the former) are auxiliaries in inspiration by raising and fixing the first and second ribs, and thus rendering them relatively immovable.

Thus, when the scaleni act, the intercostal muscles raise the ribs; when the scaleni are at rest, and the abdominal muscles act, the intercostals depress the ribs; if neither the scaleni nor abdominal muscles were to act, the ribs would be approximated at their centre by the action of the intercostal muscles.

6. The pectoralis minor (when the coracoid process is fixed), the lower costal portion of the pectoralis major, and some other muscles of minor importance might assist in elevating the ribs; but it is questionable whether they ever do so in such way as to assist in inspiration.

7. The serratus magnus has no action in inspiration; all but its lowest digitation must draw the ribs downwards, if they act on them at all.

8. The action which the sterno-mastoid is capable of exerting in inspiration is by fixing the first rib through the medium of the clavicle, and by raising the sternum. This is not required in health, but may be witnessed occasionally in disease.

9. *Expiration.*—Ordinary expiration is accomplished by the elastic resiliency of the lungs, the tense diaphragm resuming its arched form when the muscle ceases to contract: the elasticity of the ribs and abdominal parietes may assist to a limited extent; after a deep inspiration this elasticity has a more important share in expiration. The abdominal muscles, which, conjointly with the levator ani, are the agents of forced expiration, do not act by urging the abdominal viscera against the *tense* diaphragm, which would resist the pressure, to the injury of these viscera,

but against the *relaxed* diaphragm—relaxed, that is, by the abdominal muscles drawing down the lower ribs, and thus contracting the circumference of the lower part of the chest.

The intercostal muscles also contribute importantly to this result, as the effect of their contraction is reversed, by the lower ribs being relatively fixed during the action of the abdominal muscles. In this way both the long diameter and circumference of the chest are abridged.

10. The upper and lower costal movements in both sexes, when entirely unfettered, are equal, in ordinary inspiration and in the uncontracted chest.

The costal movements, both upper and lower, are much greater in forced inspiration in the male than in the female.

In both, the lower costal movements are much abridged by compression of the abdomen and lower part of the chest, while the upper costal movements are exaggerated.

The observed fact that women breathe more by the chest than by the abdomen is due to artificial compression, and to the altered form of the chest consequent on its early adoption.

February 1, 1872.

Sir JOHN LUBBOCK, Bart., Vice-President, in the Chair.

The following communications were read :—

I. "On the Lunar Variations of Magnetic Declination at Bombay." By CHARLES CHAMBERS, F.R.S., Superintendent of the Colaba Observatory. Received December 4, 1871.

(Abstract.)

This paper is in continuation of that "On the Solar Variations of Magnetic Declination at Bombay," published in the Philosophical Transactions for 1869; but the discussion is confined to the observations of the years 1861 to 1863, which alone have as yet been reduced. The point of principal interest brought out in the discussion is that whilst the mean lunar-diurnal variation is of the ordinary character, having as its principal feature a double oscillation in the lunar day, its range is very small as compared with the several ranges of the lunar-diurnal variations when the sun and moon have several specific varieties of relative position; and moreover, although in those latter variations the double oscillation is generally preserved as a main feature, correspondence of phase in the representative curves is as generally absent; and in some cases the curves are, whilst systematic, altogether different in character from the mean lunar-diurnal variation curve. The semiannual inequality in the lunar-diurnal variation,

Fig. 1.

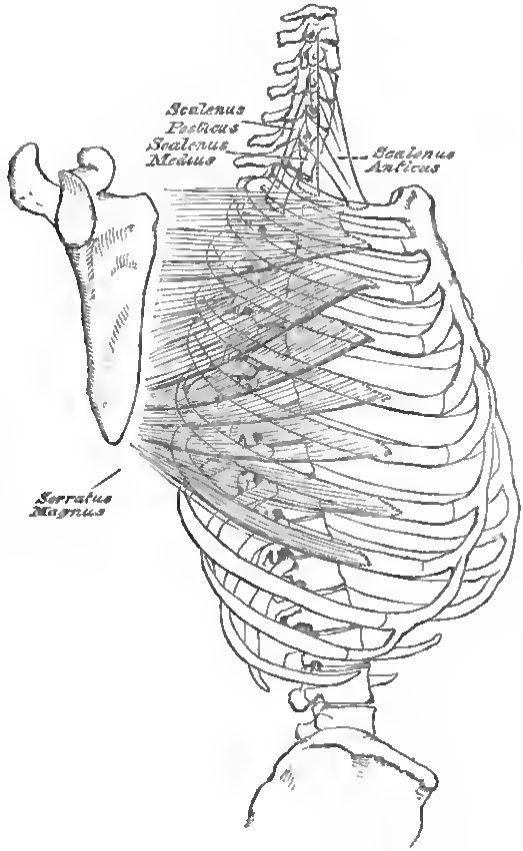

Scalenus Posticus
Scalenus Medius
Scalenus Anticus
Serratus Magnus

Fig. 2.